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EFFECTIVE DILUTION AS A POLLUTION UNIT[1]

By Wm. Firth Wells[2]

With the American practice of discharging all wastes into the natural surface waters, and the customary use of the same surface waters as a source of domestic water supply, it is essential to have accurate means of determining the permissible concentration of such wastes in waters used for various purposes. Sanitarians have adopted certain empirical criteria which are correlated with bacteriological tests for sewage organisms in determining the quality of the water. Given the daily wastes from one person in a gallon of water as the initial unit of extreme contamination, the problem reduces to the dilution of this material which shall be required before the resulting mixture may be accepted in a water supply. In a rough degree the following general proportions have been found to hold true. A dilution of one hundred times gives ordinary sewage. A dilution of sewage one hundred times gives a highly polluted river water. A dilution of a hundred times again gives a polluted river water acceptable for filtration purposes. A dilution again of a hundred times gives a water which may be acceptable for drinking purposes and another dilution of one hundred times gives a water exceeding in all tests the highest unit demanded of a water supply.

In the investigation of the dilution required in international boundary waters, Prof. E. B. Phelps developed standards of dilution according to accepted sanitary practice. Not only did he determine the dilution necessary to eliminate danger from sewage infection, but he introduced a conception which has proven very valuable in studying the relation of sewage contamination to water supply. He showed that whereas direct dilution is a primary means and measure of the elimination of the effect of pollution, other processes by reducing the infectivity of sewage may be stated in terms of "effective dilution." The ordinary water carriage sewerage system in American cities effects a dilution of a hundred gallons per capita, which constitutes the average American sewage. Simple processes of sewage treatment, such as screening and chlorination, eliminate approximately 90 per cent of the sewage organisms and, therefore, can be considered to have the same effect as, or an "effective dilution" of, ten times. Complete sewage disposal should yield a purification of 99 per cent and, therefore, can be considered to have an "effective dilution" of one hundred times. Likewise, in the treatment of drinking waters complete purification should remove 99 per cent of sewage organisms and, therefore, may be considered to have an "effective dilution" of one hundred times; while simpler processes may yield 90 per cent removal which is an "effective dilution" of ten times.

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[1] The Publication Committee has accepted this contribution because it opens up an interesting field of speculation, but this acceptance is not to be taken as an endorsement of the author's apparent position that dilution of polluted water and its treatment by storage, sedimentation, filtration and sterilization until the bacterial counts from the two treatments are alike, are practical hygienic equivalents. Comments on the paper by a member of the committee appear on page 270 of this issue. Further discussion of it is invited and should be sent to the Editor.

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It is thus seen that the dilution of the daily wastes per capita in one gallon of water to one part in ten billion of water would be considered by all sanitarians as to be beyond any reasonable probability of infection as a drinking water. A dilution of one part in a hundred million still becomes a tolerable allowance by lenient water supply standards. The dilution of one part in a million gives a water which can be suitably treated by present methods of purification to yield a satisfactory water supply. Since sewage has an "effective dilution" of one part in a hundred, and sewage treatment with an "effective dilution of one part in a hundred yields an effluent of a total "effective dilution" of one part in ten thousand, it may be seen that there remains an interval between the limits of sewage treatment and the requirements for water purification, of an "effective dilution" of one part in a hundred which must be supplied by the natural waters. This "effective dilution" must be considered the minimum requirement of river purification.

The bacterial purification of streams thus becomes a link in the problem, and it is necessary to determine the rate of disappearance of sewage organisms in a stream in order to determine the relation between time and "effective dilution." This problem was carefully worked out in the investigation of the Potomac River and a series of more than ten thousand analyses made throughout the year and corrected for various factors gave a death rate constant for B. coli, such that a 7.5-day[3] storage interval can be allowed as equivalent to an "effective dilution" of ten times. Within the zone of river purification this constant may be accepted as rigid, and for purposes of engineering calculations it may be considered a theoretical condition which may be extended into the zone of sewage treatment and water purification. In actual practice sanitarians have arrived at a time factor for storage reservoirs which may be considered the safe equivalent of efficient water purification, in which various considerations are involved other than the natural death rate of sewage organisms in the water. Likewise, in extending the practical conception of bacterial death rate within the sewage zone itself, other factors such as septic action are involved and here the relation between "effective dilution" and time is also subject to opinion. In the one case the medium itself is an interfering factor and in the other case the change either in the resistance of the organisms or factors of safety with regards to re-infection cause us to deviate in practice from results which the extension of the theoretical curve would indicate.

It thus becomes apparent that the several means by which the effect of original wastes may be eliminated, may be all stated in terms of dilution and when so stated may be given "effective dilution" equivalents. The zone of sewage is direct dilution; sewage treatment may be stated in terms of dilution; river purification or the natural death rate of sewage organisms may be considered as the relation between time and "effective dilution;" and water purification and storage may also be stated in terms of "effective dilution." In order to present these factors in a consistent manner figure 1 has been prepared. The dilution unit has been taken as one part in ten, which corresponds to a unit previously described as "dilution positive." It may be seen from a study of the figure that this unit of "effective dilution" is a reasonable and convenient one in which to consider the various stages in which the wastes are transformed or absorbed by methods of removal or elimination into drinking water. Not only is it a convenient scale on which to consider the results and steps, but it is also a convenient scale on which

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[3] The time interval allowance of 7.5 days for each "effective dilution" representing 90 per cent removal of B. coli is quite liberal. From the Potomac River curve (Hygienic Laboratory Bull. 104) the average "effective dilution" for the first six days was 0.16, while in the next 5 days it averaged 0.13 "effective dilution," and dropped to an average of 0.08 "effective dilution" for the next 4 days. Since reinfection and other factors tend to reduce the value it is more probable that a period of six days or less is equal to one "effective dilution" or a B. coli reduction of 90 per cent.

In fact, as a theoretical death rate constant, the author, from experience and knowledge of the factors involved in the Potomac River Investigation, would prefer to assume a period of five days as equivalent to one "effective dilution," or the dilution of one part in ten, or a reduction of 90 per cent. This shows the immense importance of the time factor in river purification, but a sufficiently careful analysis of experience supports the conclusion.

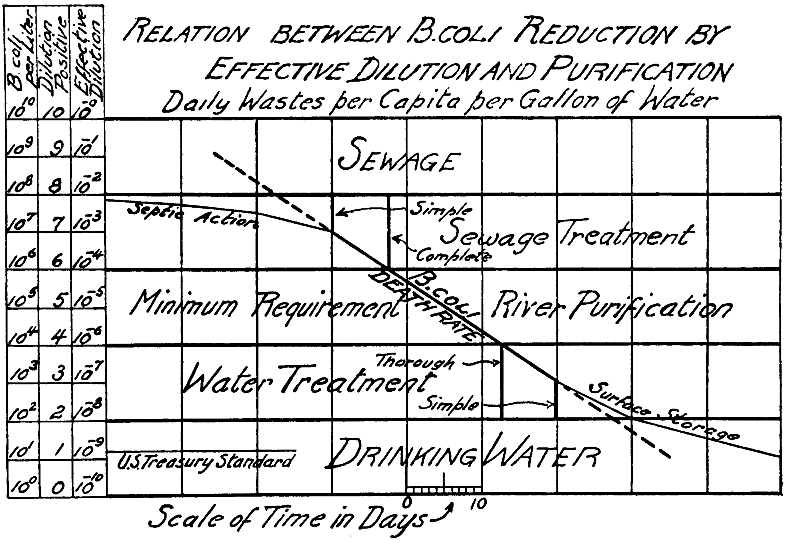

FIG. 1

to classify and compare the actual media with which sanitarians and engineers constantly are dealing. A water, for instance, which has an "effective dilution" equivalent to a "dilution positive" of five, may be considered one which by diluting ten times or by storage of 7.5 days may be suitable for efficient filtration to produce a drinking water; or by 15 days' storage, or a dilution of ten times plus 7.5 days' storage may be treated simply to produce a drinking water; or which with a dilution of ten times may be rendered suitable in storage reservoirs after thirty days storage for drinking water. Furthermore, this condition may be arrived at by diluting the per capita daily waste per gallon of water one hundred thousand times; or by diluting a completely treated sewage ten times; or by the storage for 7.5 days of a simply treated sewage which has been diluted ten times, etc. In other words, the units are interchangeable, and if the sanitarian has given an "effective dilution" equivalent to any "dilution positive" on the scale, it is a simple matter for him to determine by its location on the scale the nature of the medium with which he has to deal and the requirements necessary to produce a drinking water. Since the units are interchangeable, a very simple system is available for comparison and calculation.

Having discussed the effective dilution equivalent of water and sewage with which the engineer is concerned, it is desirable to show how they are related to the determinations of the laboratory. The bacteriologist in making his tests for B. coli, which are taken as the basis of sanitary examination, does nothing more than determine the absolute dilution necessary to eliminate the presence of this organism from his tubes. It is interesting to note that the actual steps in which he customarily makes these dilutions are precisely the same as the scale given on the chart; in fact, the "dilution positive" is a term developed because of simplicity and certain theoretical advantages in which the bacteriologist can give a statement of the results of his finding exactly as they are determined. It now appears that these statements are directly parallel to terms of "effective dilution" which the engineer uses. In other words, the conception "number of B. coli per cubic centimeter" is not at all necessary or desirable, and but leads to confusion which is too apparent when the engineer and the bacteriologist try to exchange information. If the bacteriologist merely states that he has diluted a given sample a given number of times and obtained a given "dilution positive" the engineer without puzzling over the hypothetical significance of B. coli knows exactly where on his scale of action the result is located, and the processes which will bring about such a result, and the necessary factors required to produce any condition in which he is interested. Thus the "effective dilution" of the engineer and the "dilution positive" of the bacteriologist are parallel units which make the results of one immediately available to the other.

Without going into the mathematical advantages of the results obtained by averaging and computing "dilution positives" directly, or the simplicity which it means to the laboratory man and the engineer, it may be stated for those who have any desire to arrive at an expression of the number of B. coli per liter that this result may be obtained as the antilogarithm of the "dilution positive." The reason for this is evident since the "dilution positive," because of the nature of the scale, is the logarithm of the number of B. coli per liter. Moreover, since the "average dilution positive" is the average logarithm it is the logarithm of the geometrical mean number of B. coli per liter. The theoretical reason why the geometrical mean is preferable to the arithmetical mean in the expression of B. coli results arises from the geometrical nature of the distribution of such results, and its practical advantages have been explained elsewhere.

If the bacteriologist expresses his result as the "dilution positive" in which he actually determines B. coli, and the engineer uses the same unit as an equivalent of the "effective dilution" of the daily wastes of one person in a gallon of water, each has an interchangeable unit which will simplify the expression of problems of sanitation and sanitary engineering.

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